An Analytical and Experimental Heat Recovery Integration of a Mother-Baby Plastic Granule Extruder Machine

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DECLARATION

I, **Dhamecha Bhavik Dineshbhai**, Research scholar in the Department of Mechanical Engineering, declare that the work embodied in the Ph.D. thesis entitled, **"An Analytical and Experimental Heat Recovery Integration of a Mother-Baby Plastic Granule Extruder Machine"** is my original and bonafide work carried out by me under the supervision of **Dr. Jigneshkumar J. Patel**, Professor, Dr. Subhash University and the Co-supervision of **Dr. Vipulkumar M. Patel**, Associate Professor, Dr. Subhash University for a period from *August 2022* to *March 2026* at Dr. Subhash University.

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This is to certify that the thesis entitled **"An Analytical and Experimental Heat Recovery Integration of a Mother-Baby Plastic Granule Extruder Machine"** is a bonafide record of research work carried out by **Dhamecha Bhavik Dineshbhai** (Enrol. No. **220810340004**), Research Scholar, Department of Mechanical Engineering, School of Engineering and Technology, Dr. Subhash University - Junagadh, under our supervision during the period *August 2022 – March 2026*. To the best of our knowledge: (I) the candidate has not submitted the same research work to any other University or Institute for any Degree, Diploma, Associateship, Fellowship or other similar titles (II) the thesis submitted is a record of original research work done by the Research scholar during the period of study under our supervision, and (III) the thesis represents independent research work on the part of the Research scholar.

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Abstract

Energy consumption in plastic recycling extrusion systems considerably effects operational cost and process sustainability. In mother–baby extrusion arrangements, an inter unit open space exists between the mother and baby extrusion units, which may lead to confined thermal losses and increased heater energy demand. On the other hand, efficient experimental identification and analytical assessment of such heat loss areas under industrial conditions remain limited.

The present research studies thermal behavior and energy performance of a mother–baby plastic granules extrusion system working under real industrial recycling situations. Experimental quantities of baby unit inlet temperature were conducted for six consecutive days before and after integration of a structural heat recovery solution, with eight readings recorded per day. The inter unit open space was identified as the major heat loss space, and a recovery structure was designed and implemented to minimize thermal losses.

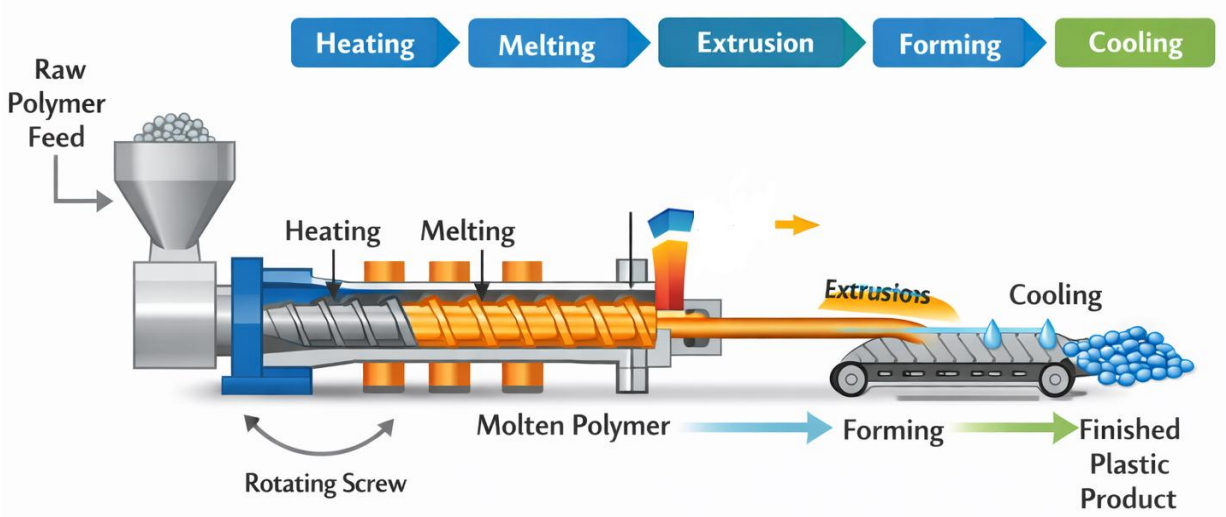
An analytical heat transfer model was designed including conduction through the barrel wall, conduction from barrel inner surface to polymer, convective heat transfer induced by screw rotation, and internal heat generation due to friction and shear within the polymer. Heat transfer rate was calculated using mass flow rate and temperature differential. Relative analysis validated a rise in baby unit inlet temperature after structural integration, resulting in reduced heater energy demand and lower specific energy consumption (SEC). While calculated thermal efficiency indicated variation due to reduced external heater dependency, overall energy utilization of the system enhanced.

This study creates a controlled methodology for confined heat loss identification, analytical modeling, and industrial validation of heat recovery integration in multi stage plastic extrusion systems.

Chapter 1

Introduction

Plastic recycling has become progressively important due to the quick growth in plastic utilization and the related environmental concerns. Recycling procedures help decrease plastic waste and protect natural resources by converting unwanted plastic materials into reusable products. Among many recycling technologies, extrusion is one of the best and widely used processes for converting plastic waste into granules that can be reused in industrial applications.

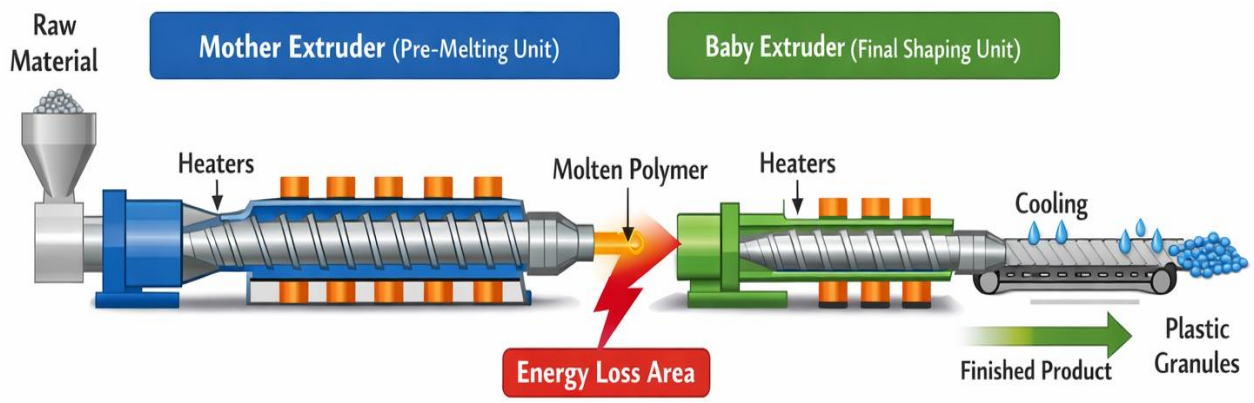


[Figure 1.1: Schematic Representation of a Plastic Granule Extrusion System]

In plastic recycling industries, the mother-baby plastic granules extrusion system is usually employed due to its capacity to process mixed and contaminated plastic materials efficiently. In this system, the mother unit completes the primary melting and mixing of the plastic waste, while the baby unit additional refines the molten polymer before it is converted into granules. During this process, considerable thermal energy is required to increase the polymer temperature to the required melting level and maintain steady processing conditions. This heat is mainly supplied by electrical heaters attached on the barrel and is supplemented by mechanical energy generated due to screw rotation.

On the other hand, an important portion of the supplied heat is regularly lost to the surrounding environment during the extrusion process. These heat losses reduce the overall thermal efficiency of the system and increase the specific energy consumption. In industrial mother-baby extrusion

machines, the open structural region between the mother and baby units can act as a possible source of heat loss, as it permits thermal energy from the high temperature polymer flow and connecting components to dissipate into the environment. Understanding the heat transfer performance within the extrusion system is therefore crucial for improving energy efficiency. Heat transfer in extrusion processes includes multiple mechanisms, including conduction through the barrel wall, conduction between the barrel surface and polymer melt, convective heat transfer caused by screw rotation, and heat generation due to friction and shear within the polymer.



[Figure 1.2: Schematic Representation of a Mother-Baby Plastic Granule Extrusion System]

The present work focuses on the analytical and experimental investigation of heat transfer in a mother-baby plastic granules extrusion machine. By joining analytical modeling with experimental observations, the study contributes toward improving thermal efficiency and decreasing specific energy consumption in plastic extrusion based recycling systems.

Chapter 2

Literature Review

Focused Area	Key Findings from Literature	Representative References
Basics of Polymer Extrusion	Basic extrusion mechanisms including melting, conveying and pressure development are explained. Screw geometry and barrel heating effect the melting performance and product quality.	[1], [4], [7], [12], [18], [23]
Heat Transfer in Extrusion Systems	Heat transfer inside extruders happens through heater conduction, barrel conduction, convection due to screw rotation and viscous dissipation. Thermal control is serious for proper polymer melting.	[2], [6], [9], [14], [19], [27], [33]
Polymer Melting Performance	Studies define the solid bed melting mechanism and temperature gradients beside the extruder barrel. Precise prediction of melting helps in develop product quality and reduce degradation.	[3], [8], [15], [21], [28], [35]
Energy Uses in Extrusion	Extrusion procedures require substantial energy, mainly for heaters and screw drive motors. Some studies highlight the significance of improving operating constraints to reduce energy usage.	[5], [10], [17], [24], [29], [36], [41]
Specific Energy Consumption Reduction	Researchers inspected methods to reduce SEC through screw design enhancement, adjusted temperature profiles, and well material feeding methods.	[11], [16], [22], [30], [37], [44], [48]
Numerical and Analytical Modelling	Mathematical and computational models are used to simulate temperature supply, pressure change, and melting inside extrusion systems.	[13], [20], [26], [32], [38], [45], [52]
Experimental Studies on Extruders	Experimental quantities of temperature, pressure, and energy consumption supports in validate theoretical models and gives practical insights for engineering extrusion processes.	[25], [31], [39], [42], [46], [50], [55]
Plastic Recycling using Extrusion	Extrusion is broadly used in plastic recycling processes to transform waste plastics into granules. Thermal control and process stability are important for keeping recycled polymer quality.	[34], [40], [43], [47], [49], [53], [57]
Heat Recovery and Waste Heat Utilization	Waste heat recovery from manufacturing systems can meaningfully improve energy efficiency and decrease operating costs.	[51], [54], [56], [58], [60], [62]
Sustainable Polymer Processing	Recent work highlights sustainable manufacturing by improving thermal efficiency, reducing energy losses, and integrating process optimization methods.	[6], [18], [27], [41], [52], [59], [61], [63]

Chapter 3

Research Gap and Problem Identification

Plastic recycling engineering usually work with single screw extrusion systems, including multi stage mother-baby arrangements, for the manufacture of plastic granules. In practical industrial situations, an open inter unit space exists between the mother and baby extruder units through which the semi molten polymer is transferred. This region is normally exposed to the surrounding atmosphere and absences any structured thermal management. As a result, heat loss occurs, increasing the heater load requirement of the downstream unit (baby unit) and donating to higher specific energy consumption [5], [6], [18].

Even if earlier research has extensively addressed process parameter optimization, screw design improvement, and advanced control strategies, but very limited attention has been given to identifying heat loss in inter unit transfer regions of multi stage extrusion systems [7], [8], [10]. Also in extrusion, heat transfer is directed by multiple interrelating mechanisms, including conduction through the barrel wall, heat transfer from barrel inner surface to the polymer, convective heat transfer induced by screw rotation, and internal heat generation due to friction and shear within the polymer melt [3], [4], [13], [33].

Therefore, the essential problem addressed in this research is to experimentally measure the thermal behavior of the baby unit inlet region before and after structural heat recovery integration, and to analytically evaluate the heat transfer mechanisms governing the system.

Therefore, the essential problems addressed in this research are to:

1) Experimentally identify the maximum heat loss occurring in the inter unit open space,
2) Design and implement a structural heat recovery solution,
3) Analytically calculate the heat transfer mechanisms before and after integration using $\dot{Q} = \dot{m} \cdot C_p \cdot \Delta T$,
4) Calculate the impact on heater energy demand, specific energy consumption, and thermal efficiency under real industrial situations.

Chapter 4

Objectives and Scope of the Work

Objectives of the Work

The objectives of this research work is to improve the energy performance of a mother-baby plastic granules extrusion system used in recycling applications through analytical and experimental investigation.

The specific objectives are:

1) To identify the maximum heat loss occurring in the inter unit open space between the mother and baby extrusion units then design and implement a structural heat recovery solution to minimize confined heat loss in the inter unit region [3], [5], [8].
2) To experimentally measure the baby unit inlet temperature under industrial working situations before and after integration of a heat recovery structure over multiple days to validate analytical models [7], [10], [14].
3) To create an analytical heat transfer model for the mother-baby extrusion system incorporating [1], [2], [4], [6]:
    a) Conduction heat transfer from the barrel outer surface to barrel inner surface.
    b) Conduction heat transfer from the barrel inner surface to the raw plastic.
    c) Convective heat transfer from barrel inner surface to solid material, induced by screw rotation.
    d) Internal heat generation due to friction and shear within the polymer during screw rotation.
4) To evaluate the heat transfer rate using $\dot{Q} = \dot{m} \cdot C_p \cdot \Delta T$, before and after heat recovery integration [30], [37].
5) To calculate the impact of structural heat recovery on heater energy demand, specific energy consumption (SEC), and thermal efficiency [11], [16], [22], [44].

Scope of the Work

This research is limited to the analytical and experimental investigation of heat transfer and energy performance in a mother–baby plastic granules extrusion system operating under industrial recycling situations.

The scope includes:

1) Temperature measurement at the baby unit inlet for three days before and three days after integration of the heat recovery structure, with eight readings per day.
2) Development of an analytical heat transfer model representing conduction, convection, and internal heat generation mechanisms.
3) Calculation of heat transfer rate using mass flow rate and temperature difference.
4) Study of heater energy demand, specific energy consumption, and thermal efficiency based on measured industrial data.

This work does not contain any numerical CFD simulation, modification of screw geometry, material rheology alteration, or advanced control algorithm development. The research focuses specifically on structural heat loss identification and heat recovery integration in the inter unit open space.

Chapter 5

Industrial Setup and Intermediary Heat Integration

All research and experimental work was conducted in collaboration with **Windson Machinery Manufacturing,** located at **Dhoraji**, providing hands on exposure, real time process measurements and validation of heat recovery and energy efficiency improvements. This experimental system consists of a mother–baby plastic granules extruder used in plastic recycling industry. The system includes two single screw extruders connected in series.

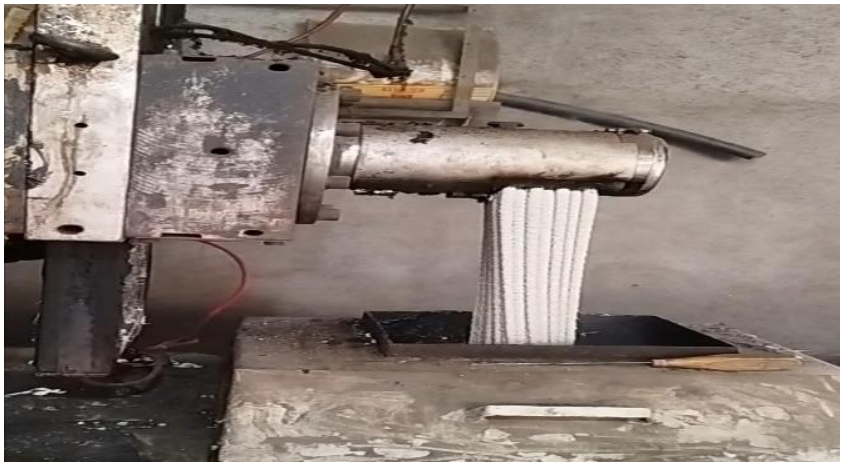
5.1 Experimental Setup

The experimental study was conducted on a Mother-Baby plastic granule extruder system used in industrial scale LDPE recycling. The system includes a primary mother unit for initial plastic melting and a secondary baby unit for refining and shaping the molten plastic into granules.

[Figure 5.1: Overall view of Mother-Baby Plastic Granule Extruder (Industrial Setup)]

Figure 5.1 demonstrates the industrial setup of the plastic recycling machine used in the present experimental investigation. The system mainly consists of a feeding unit, mother extruder, baby extruder, heating elements, and a die assembly. The setup is designed to process waste plastic material and convert it into reusable plastic granules through a continuous extrusion process.

The waste plastic material is first supplied to the machine through the feeder, from where it enters the mother extruder. The mother extruder is furnished with a rotating screw housed inside a heated barrel. Multiple electrical heaters are attached along the barrel to provide the required thermal energy for softening and melting the plastic material. The joined effect of external heating and internal shear generated by screw rotation confirms unchanging melting of the polymer.



[Figure 5.2: Open Space between Mother-Baby Plastic Granule Extruder before Heat Recovery Integration]

The moderately processed molten plastic from the mother extruder is then moved to the baby extruder, which further regulates the material and stabilizes the melt flow. Similar to the mother unit, the baby extruder is also fitted with barrel heaters to maintain the required processing temperature. The molten plastic leaving the baby extruder is forced through a die, forming continuous elements. Figure 2 shows that the open space between mother and baby unit.

5.2 Design and Impact of Intermediary Thermal Structure between Mother and Baby Units

a) Introduction

In mother-baby extruder, a significant thermal energy dissipation occurs between the two units due to the open space arrangement. This open gap leads to heat losses, mostly in the transition zone where the heated polymer exits the mother unit and enters the baby unit. Identifying this inefficiency, an intermediary structure was designed and implemented to thermally separate and keep the heat transfer pathway.

b) Structural Description and Materials

The designed structure is a semi enclosed thermally insulated chamber installed accurately in the interface region between the outlet of the mother unit and the inlet of the baby unit. Its main objectives are:

I. To minimize heat losses from the extrudate during transfer.
II. To preheat the baby unit inlet zone using ambient thermal recovery.
III. To act as a thermal shield zone, hence reducing the required heat input in the baby unit.

[Figure 5.3: Intermediary Thermal Structure]

c) Broader Consequences and Research Value:

This structural innovation works as a practical demonstration of applied heat recovery and loss minimization. In the industry, this low cost, high control modification can be protracted to various types of multi stage extrusion lines where inter unit thermal interaction is underutilized.

[Fig. 5.4: Assembled view of Mother-Baby unit with Heat Recovery Structure (Integrated Setup)]

Chapter 6

Analytical Methodology with Validation Approach

6.1 Analytical Methodology and Assumptions

The heat transfer analysis in this study is divided into the following four stages for both the mother and baby units:

I. Conduction heat transfer from the barrel outer to barrel inner surface.
II. Conduction heat transfer from the inner barrel surface to the raw plastic.
III. Convective heat transfer from inner barrel surface to solid material, induced by screw rotation.
IV. Internal heat generation due to friction and shear within the polymer during screw rotation.

a) Governing Equations Used

I. Conduction heat transfer from the outer barrel to inner barrel surface:

$$Q = \frac{2\pi kL\,(T_{\text{barrel outer}} - T_{\text{barrel inner}})}{\ln(\frac{r_{\text{outer}}}{r_{\text{inner}}})} \quad (1)$$

II. Conduction heat transfer from the inner barrel surface to the raw plastic:

$$Q = \frac{kpA(T_{\text{barrel inner}} - T_{\text{raw material}})}{X} \quad (2)$$

III. Convective heat transfer from inner barrel surface to solid material, induced by screw rotation.

$$Q = h \cdot A\,(T_{\text{inner}} - T_{\text{polymer}}) \quad (3)$$

IV. Frictional Heat Generation

$$Q = \eta \times P \quad (4)$$

V. Overall useful heat transfer:

$$Q_{useful} = Q_{cond\ polymer} + Q_{conv} \quad (5)$$

VI. Total heat supplied:

$$Q_{total\ heat} = Q_{cond\ inner} + Q_{shear} \quad (6)$$

b) Key Assumptions

To easy the analysis and to design a practical thermal model of the extrusion system, the below assumptions were considered in this study.

The operation of the extrusion machine was assumed to be under steady state conditions, where temperatures and heat transfer rates remain constant with time. Perfect thermal contact between the heater, barrel surface, and the processing material was assumed to remove any contact resistance. The material properties were considered uniform throughout the analysis. Heat transfer through the barrel wall and the polymer melt was assumed to follow in one dimensional (1D) radial direction. The influence of thermal radiation was considered negligible compared to conduction and convection mechanisms. Also, a steady heater load was assumed during procedure to maintain stable thermal conditions within the extrusion system.

6.2 Validation Approach

The calculated values for heat fluxes (Q) in each mode were compared before and after the structural enclosure was implemented. This allowed validation of the analytical model through observed differences in:

I. Inlet temperature at baby unit.
II. Heater energy demands.
III. Specific energy consumption (SEC).
IV. Thermal efficiency.

Chapter 7

Experimental Study and Performance Assessment

7.1 Data Collection and Input Parameters

[Table 7.1: Complete Set of Readings for Mother-Baby Plastic Granule Extruder]

Sr. No.	Parameter	Value		Parameter Unit
		Mother Unit	Baby Unit	
1	Barrel inside diameter	150	135	mm
2	Barrel outside diameter	240	215	mm
3	Barrel length	14	5	Ft
4	Inlet temperature	53	129	℃
5	Outlet temperature	140	144	℃
6	Barrel outer temperature	146	151	℃
7	Barrel inner temperature	130	143	℃
8	Heater temperature	165	165	℃
9	Running load	75	25	HP

7.2 Experimental Temperature Readings

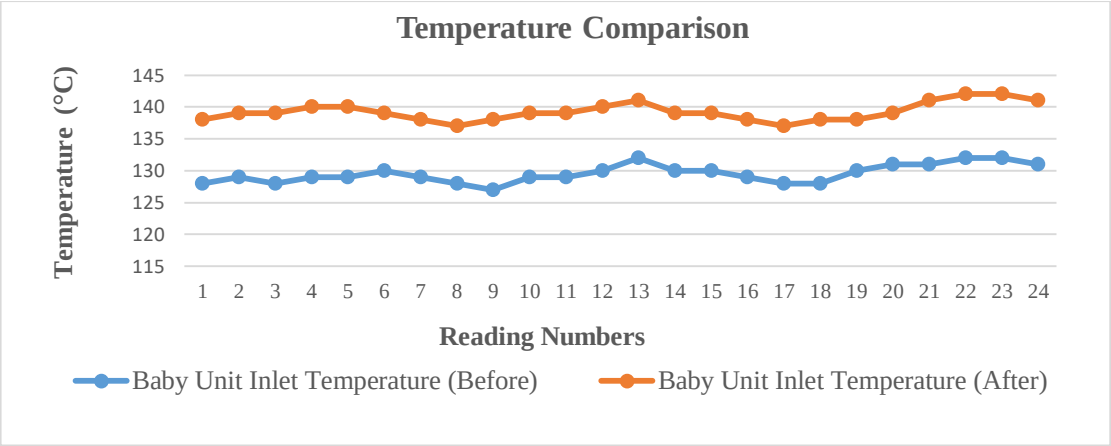
a) Temperature readings were recorded for six consecutive days from 6th July, 2025 to 12th July, 2025 at one hour intervals (8 readings/day) and readings were collected before and after integration of the heat recovery structure.

b) Minor fluctuations in readings indicate real time operational variations in the extrusion process. Also ttemperature sensors were placed at the outlet of the mother unit, inlet and outlet of the baby unit.

[Figure 7.1: Temperature Sensor Placement (Randomly)]

[Table 7.2: Average Experimental Values for Baby Unit Temperature before and after Structure Installation]

		Baby Unit Inlet Temperature (˚C)	Baby Unit Outlet Temperature (˚C)	ΔT Across Baby Unit (˚C)
Before Structure Installation	6th July, 2025	128.75	144.00	15.25
	7th July, 2025	129.50	144.00	14.50
	8th July, 2025	130.38	144.00	13.62
	Average	**129.54**	144.00	**14.46**
After Structure Installation	10th July, 2025	138.75	144.00	5.25
	11th July, 2025	139.12	144.00	4.88
	12th July, 2025	139.73	144.00	4.27
	Average	**139.00**	144.00	**5.00**
Improvements		Temperature increased (09.46 ˚C)	Same as maintained	Reduced load on heater



[Figure 7.2: Time wise Comparison of Baby Unit Inlet Temperature before Structure and after Structure Installation]

Figure 7.2 shows the inlet temperature comparison of the baby unit before and after integration of the heat recovery structure. A noticeable increase in inlet temperature was observed post structure, indicating successful recovery of thermal energy that would otherwise be lost. This contributed to improved thermal performance and reduced energy consumption in the baby unit.

7.3 Heat Transfer Calculations

a) For Mother Unit:

I. Conduction heat transfer from the barrel outer to inner surface = 35.89 kW

II. Conduction heat transfer from the barrel inner surface to raw plastic = 37.94 kW

III. Convective heat transfer from barrel inner surface to solid material = 9.3 kW

IV. Frictional heat generation = 33.57 kW

b) For Baby Unit (Before Heat Recovery Structure Integration):

I. Conduction heat transfer from the barrel outer to inner surface = 6.38 kW

II. Conduction heat transfer from the barrel inner surface to raw plastic,

- Day-1 [6th July, 2025] (Average) = 2.50 kW
- Day-2 [7th July, 2025] (Average) = 2.37 kW
- Day-3 [8th July, 2025] (Average) = 2.22 kW

III. Convective heat transfer from barrel inner surface to solid material,

- Day-1 [6th July, 2025] (Average) = 0.81 kW
- Day-2 [7th July, 2025] (Average) = 0.77 kW
- Day-3 [8th July, 2025] (Average) = 0.72 kW

IV. Frictional heat generation = 11.19 kW

c) For Baby Unit (After Heat Recovery Structure Integration):

I. Conduction heat transfer from the barrel outer to inner surface = 6.38 kW

II. Conduction heat transfer from the barrel inner surface to raw plastic,

- Day-1 [10th July, 2025] (Average) = 0.75 kW
- Day-2 [11th July, 2025] (Average) = 0.69 kW
- Day-3 [12th July, 2025] (Average) = 0.58 kW

III. Convective heat transfer from barrel inner surface to solid material,

- Day-1 [10th July, 2025] (Average) = 0.25 kW
- Day-2 [11th July, 2025] (Average) = 0.23 kW
- Day-3 [12th July, 2025] (Average) = 0.19 kW

IV. Frictional heat generation = 11.19 kW

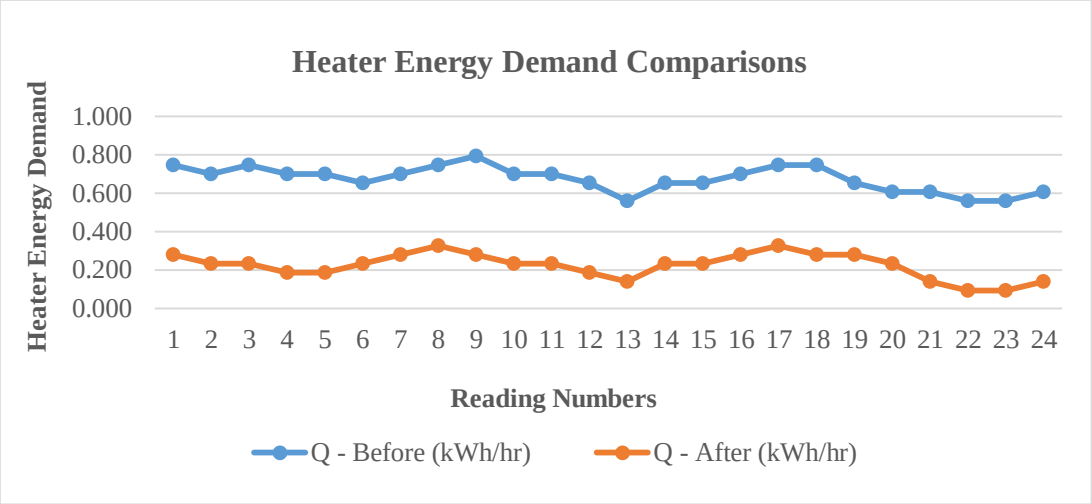
7.4 System Performance Analysis

a) Reduction in Heater Energy Demand:

The heat transfer rate was evaluated using $\dot{Q} = \dot{m} \cdot C_p \cdot \Delta T$. Since the mass flow rate (80 kg/hr as per extruder capacity) and specific heat capacity were maintained constant throughout the experiments, variations in $\dot{Q}$ directly affects changes in the temperature rise supplied by the barrel heaters.

[Table 7.3: Values of $\dot{Q}$ with Baby Unit Inlet Temperature before Structure and after Structure Installation]

Day	Baby Inlet Temperature [Before Structure]	Baby Inlet Temperature [After Structure]	ΔT [Before]	ΔT [After]	$\dot{Q}$ in kWh/hr [Before]	$\dot{Q}$ in kWh/hr [After]
Day 1	128.750	138.750	15.250	5.250	0.711	0.245
Day 2	129.500	139.125	14.500	4.875	0.676	0.227
Day 3	130.375	139.750	13.625	4.250	0.635	0.198
Average	**129.541**	**139.208**	**14.450**	**4.800**	**0.674**	**0.223**



[Figure 7.3: Comparison of Heater Energy Demand before Structure and after Structure Installation]

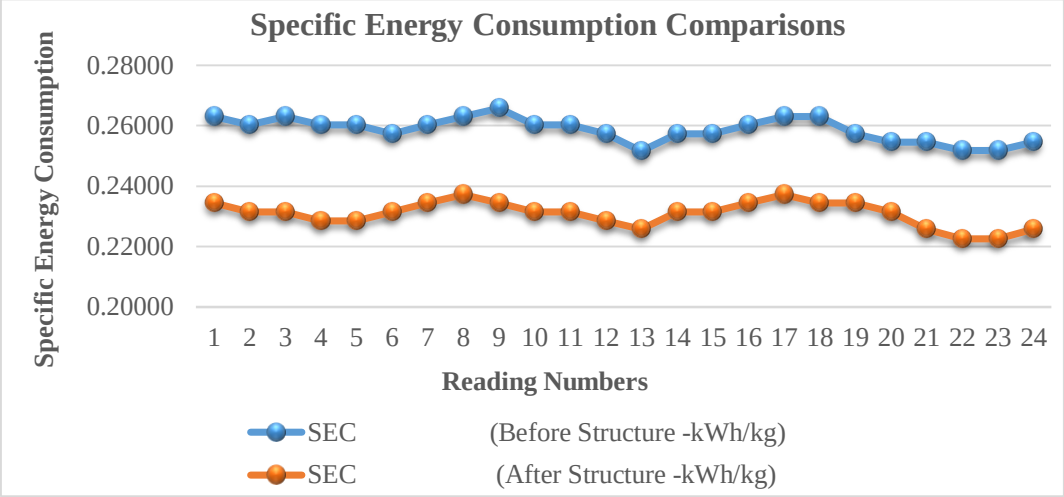
b) Specific Energy Consumption:

$$\text{S. E. C.} = \frac{\text{Total Heat Supplied (kW/h)}}{\text{Mass of Output (kg)}}$$

- Mass of output = 80 kg (As per machine capacity),

[Table 7.4: Values Specific Energy Consumption before Structure and after Structure Installation]

Day	SEC in kWh/kg (Before Structure)	SEC in kWh/kg (After Structure)	Δ SEC (kWh/kg)
Day 1	0.26103	0.23214	0.02890
Day 2	0.25884	0.23105	0.02780
Day 3	0.25638	0.22923	0.02710
Average	**0.25875**	**0.23080**	**0.02793**


Specific Energy Consumption Comparisons
Specific Energy Consumption
0.28000
0.26000
0.24000
0.22000
0.20000
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Reading Numbers
SEC (Before Structure -kWh/kg)
SEC (After Structure -kWh/kg)

[Figure 7.4: Comparison of Specific Energy before Structure and after Structure Installation]

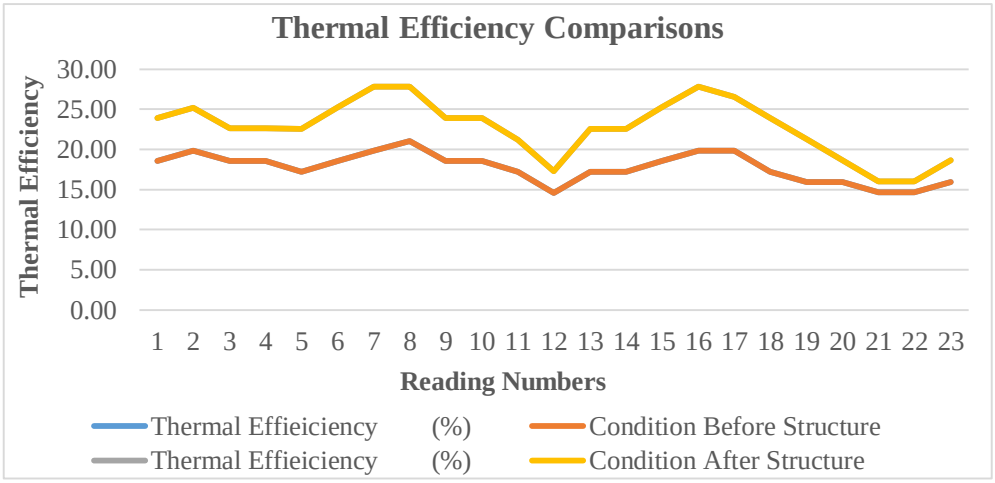
c) Thermal Efficiency:

In this study, thermal efficiency was calculated based on a detailed heat transfer analysis that considered both conductive and convective mechanisms inside the extruder system.

$$\eta_{thermal} = \frac{\text{Useful Heat to Plastic}}{\text{Total Heat Supplied}} \times 100\ \%$$

[Table 7.5: Values Thermal Efficiency before Structure and after Structure Installation]

Day	Thermal Efficiency [Before Structure]	Thermal Efficiency [After Structure]	Change in Thermal Efficiency
Day 1	18.85	5.70	13.15
Day 2	17.86	5.20	12.66
Day 3	16.73	4.38	12.35
Average	**17.81**	**5.09**	**12.72**



[Figure 7.5: Comparison of Specific Energy before Structure and after Structure Installation]

Chapter 8

Results and Discussions

8.1 Results

[Table 8.1: Summary of System Performance Analysis]

Sr. No.	Parameter	Before Structure	After Structure	Change (%)
1	Reduction in Heater Load (kWh/hr.)	0.674	0.233	65.40
2	Specific Energy Consumption (kWh/kg)	0.25875	0.23081	10.80
3	Thermal Efficiency (%)	17.81	5.09	71.42

8.2 Discussions

a) Overview

This presents the key results derived from the analytical heat transfer study, compares pre- and post-structural modification data and discusses the effects on energy performance, thermal behaviour and overall process efficiency. The analytical results were validated through observed temperature improvements, reduced heater duty cycles, and specific energy consumptions. All findings are interpreted in the perspective of industrial plastic recycling applications and sustainability.

b) Temperature Behaviour and Heat Transfer Analysis

The installation of the intermediary thermal structure between the mother and baby extruder units led to a notable increase of 9.46 °C in the baby unit's inlet temperature from 129.54 °C to 139 °C. This increase was recognized to the recovery of heat losses that previously lost into the open environment.

c) Reduction in Heater Load

An important reduction in heater load was observed after the implementation of the structure. The heater energy requirement decreased from 0.674 kWh/hr. in the conventional configuration to 0.233 kWh/hr. After implementation, resulting in an absolute reduction of 0.451 kWh/hr.

d) Specific Energy Consumption (SEC) Improvement

Specific Energy Consumption, a serious parameter for evaluating process energy efficiency, decreased from 0.25875 kWh/kg to 0.23081 kWh/kg, conforming to a reduction of 0.02794 kWh/kg.

e) Thermal Efficiency

After the implementation of the heat recovery structure, the calculated thermal efficiency value reduced from 17.81 % to 5.09 %. This reduction does not indicate worsening of system performance but it reflects an important reduction in the required external heat input due to effective recovery and reutilization of previously lost thermal energy.

Chapter 9

Conclusions

a) The heat recovery structure provides a practical and sustainable solution for improving energy utilization in mother–baby plastic granule extruders.

b) Integration of the system enables optimized energy distribution, demonstrating that industrial polymer processing can be made more efficient without major equipment modifications.

c) Experimental results and analytical models together validate the effectiveness of the design, offering a robust framework for future energy-efficient extrusion strategies.

d) The proposed approach is technologically feasible, environmentally friendly and ready for industrial implementation, marking a significant step toward sustainable polymer processing.

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Paper Published

Sr. No.	Paper Title	Journal/ Conference	Indexed	Year of Publications	ISSN	Volume	Issue
1	A Review, Thermal Equivalence of Extrusion Process in Single Screw Extruder	International Conference	-	2024	-	-	-
2	Heat Transfer Analysis and Experimental Evaluation of a Mother-Baby Plastic Granule Extruder Incorporating Heat Recovery	International Journal of Applied Bioanalysis	Scopus	2025	2405-710X	11	15
3	Waste Heat Utilization for Improving Thermal Efficiency and Reducing Energy Consumption in Plastic Granule Extrusion: An Experimental Approach	International Journal of Natural Sciences	Web of Science	2026	0976-0997	16	94
4	An Analytical and Experimental Heat Transfer Investigation of a Mother-Baby Plastic Granule Extruder Machine with Heat Recovery Integration	International Journal of Natural Sciences	Web of Science	2026	0976-0997	17	95